

# Observations of Shear-Induced Turbulence using HARLIE

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## ABSTRACT

Ground-based measurements of atmospheric aerosol structure were made using the Holographic Airborne Rotating Lidar Instrument Experiment (HARLIE) during the HOLO-1 field campaign. The scanning ability of HARLIE affords a unique opportunity to view various atmospheric phenomena. Shear-induced turbulence plays an important role in the transport of kinetic energy in the atmosphere and on March 10, 1999, several instances of shear-induced turbulence were observed via HARLIE. Using the data collected and upper-air wind profiles the nature of the instabilities is discussed.

## 1. Introduction

Shear-induced instabilities are a common occurrence in the atmosphere. Occurring between two stably-stratified layers ( $\delta\rho/\delta z < 0$ ), these instabilities amplify at the expense of the kinetic energy of the mean flow and dissipate their energy into small-scale turbulence. In the absence of continued forcing, this diffusion reduces the shear between the layers. However, if the forcing continues, these instabilities can persist for hours. Often referred to as clear-air turbulence, these instabilities have made themselves known to many commercial airline passengers.

Scanning lidars have the ability to observe the atmosphere in two or three dimensions affording a unique view of atmospheric aerosol structure. The Holographic Airborne Rotating Lidar Instrument Experiment (HARLIE) was constructed to test the feasibility of using holographic scanning receivers in lidar systems (Schwemmer, 1998) as opposed to conventional telescopes.

On March 10, 1999, during the HOLO-1 field campaign in Logan, UT, several instances of shear-induced instabilities were observed using HARLIE. These observations are discussed by means of the data collected via HARLIE and the meteorological data for the period.

## 2. Instrument Description

HARLIE uses a 40 cm diameter transmission holographic optical element (HOE) as the collecting and focusing aperture (Figure 1).

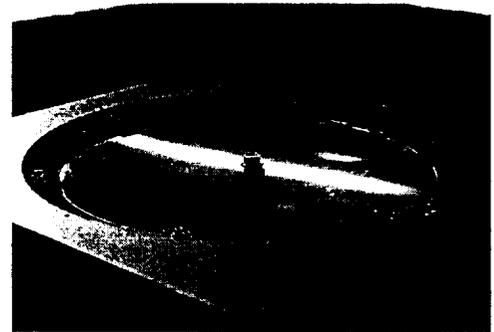


Figure 1: HARLIE Holographic Optical Element (HOE)

The HOE has a 45-degree diffraction angle and is rotated during operation resulting in a conical scan of the atmosphere. Figure 2 shows the electronics rack and transceiver assembly.

The laser is a 2 mJ, 1064 nm Nd:YAG pulsed at 5 kHz. The output of a single Geiger-mode avalanche photodiode detector is ping-ponged between two multi-channel scalars. A profile each 0.10 second is produced by accumulating photo-counts for 500 shots. The rotation rate was  $10^\circ$  per second yielding one profile per azimuth degree and the range resolution is 30 m yielding a  $\sim 21$  m vertical resolution.

## 3. Experiment Environment

The principal objectives of the HOLO-1 campaign were to evaluate the performance of HARLIE and to aid in the

development of new applications for conical scanning aerosol lidars. HARLIE was operated alongside the Army Research Office Lidar (AROL-2) zenith-pointing static lidar to allow for intercomparison with its more conventional measurements.

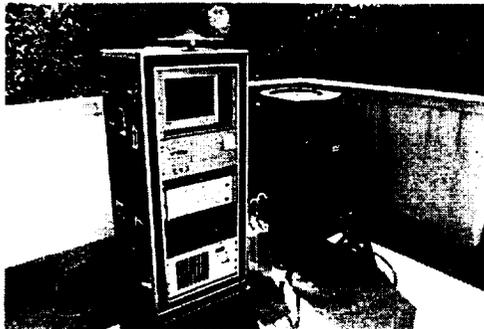


Figure 2: HARLIE electronics rack (left) and transceiver assembly (right).

The data presented here were collected during the HOLO-1 field campaign held at the Space Dynamics Lab (SDL) in Logan, UT. Logan is located in Cache Valley approximately 100 km north of Salt Lake City, UT. The town is at an elevation of ~1400 m above sea level (ASL) and sits at the foot of the Wasatch Mountain Range with nearby peaks reaching ~2700 m ASL. About 15 km to the west of Logan is the Wellsville Mountain Range with peaks reaching ~2850 m ASL. These mountain ranges play an important role in the atmospheric dynamics of Cache Valley.

In-situ measurements of atmospheric parameters (e.g., temperature, humidity, and winds) were not recorded during HOLO-1. Meteorological observations from the nearest National Weather Service observing site, located in Salt Lake City, are used in this discussion.

#### 4. Observations

According to the 1200 UTC upper-air soundings, there was strong wind shear in the vertical between 500 mb (~5.6 km ASL) and 300 mb (~9.2 km ASL).

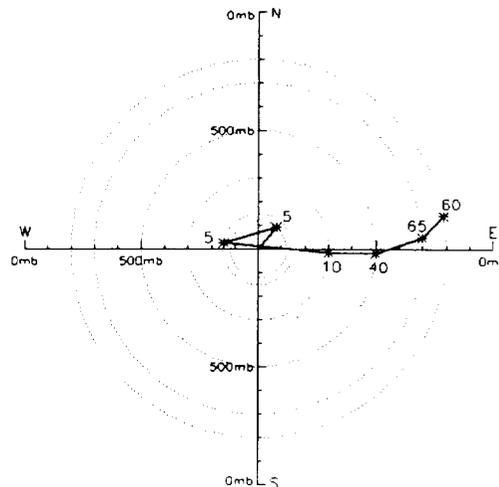


Figure 3: 3/10/99, 1200 UTC hodograph of Salt Lake City wind data. Points (\*) represent the wind direction and the number is the wind velocity in knots at that level. The rings are pressure levels with the innermost ring representing the surface.

Figure 3 is a hodograph of the Salt Lake City wind data. A hodograph shows the wind direction for each level, with the wind velocity in knots indicated beside each point. Strong wind shear in the vertical frequently produces shear instabilities between stably-stratified layers.

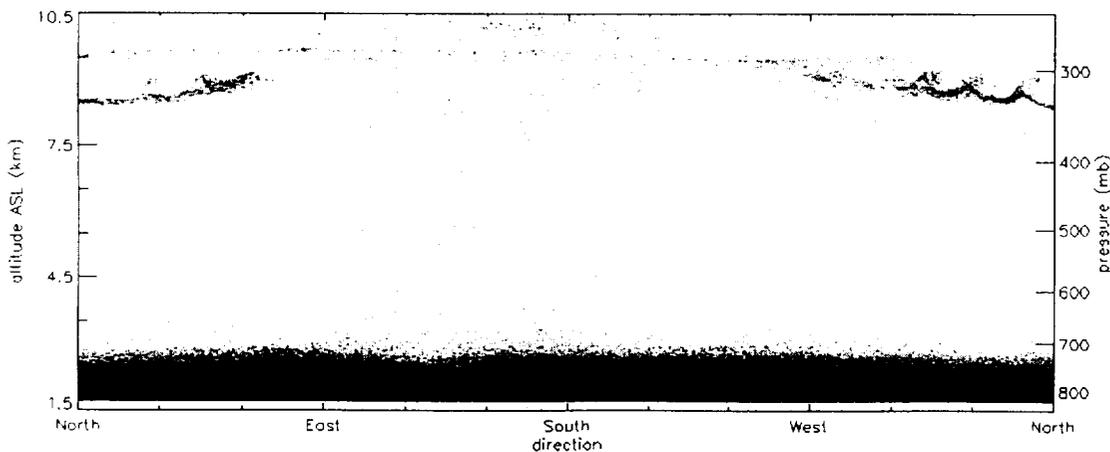


Figure 4: Atmospheric scan from 3/10/99 at 1650 UTC showing Kelvin-Helmholtz waves at ~9.0 km ASL.

The instabilities begin as undulations in the interface between the layers, and, if the forcing continues, the instabilities at the interface amplify. Occasionally, the instabilities will roll up into billows often referred to as Kelvin-Helmholtz (K-H) waves.

A striking example of this is shown in Figure 4 at 9 km ASL. The figure shows relative backscatter from aerosols in the atmosphere. Be aware that there are distortions in Figure 4 as a result of displaying a conical scan as a rectangular image. The pressure ordinate is based on the U. S. Standard Atmospheric model and not on actual measurements.

The waves grow at the expense of the kinetic energy of the mean flow and eventual break down into small-scale turbulence. The waves illustrated in Figure 4 occurred at a typical cruising altitude of commercial aircraft. However, the turbulence felt on airplanes in flight is due to the small-scale turbulence, not the large billows (Wallace and Hobbs, 1977).

Another example of shear-induced turbulence occurred later in the day, between 2300-0100 UTC. There were both velocity and directional vertical shear present between 700 mb (~3 km ASL) and 500 mb (~5.6 km ASL) as seen in the 0000 UTC hodograph for Salt Lake City (Figure 5).

As the afternoon progressed, the bottom interface of the layer began to undulate. These undulations are apparent in Figure 6 as small wavelike features along the bottom interface around 5.5 km. Approximately an hour later, the bottom interface broke down into turbulence (Figure 7). The general wavelike appearance of the layer is caused by the southeasterly flow over the Wasatch Mountains at 850mb.

## 5. Summary

Shear-induced instabilities play an important role in the transfer of momentum in the atmosphere. Several

occurrences of instabilities were observed via HARLIE proving that a scanning backscatter lidar is a powerful tool for studying atmospheric dynamics. These cases were discussed in the context of the meteorological environment of when they were observed.

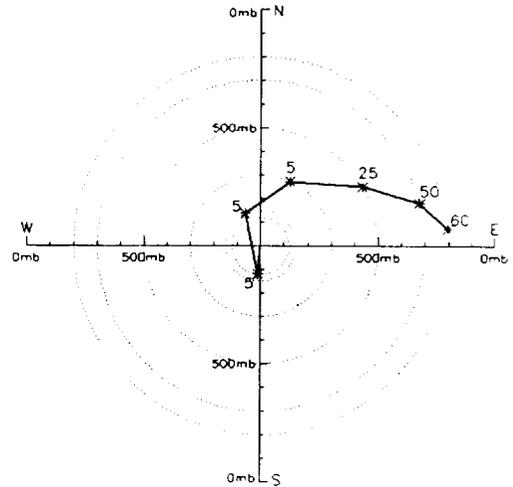


Figure 5: 3/11/99, 0000 UTC hodograph of Salt Lake City wind data.

The development of an algorithm to derive horizontal-wind profiles in the vertical from HARLIE data recorded during HOLO-1 is currently underway. Future work will include combining HARLIE data and local meteorological measurements to allow for a more detailed analysis of atmospheric dynamics.

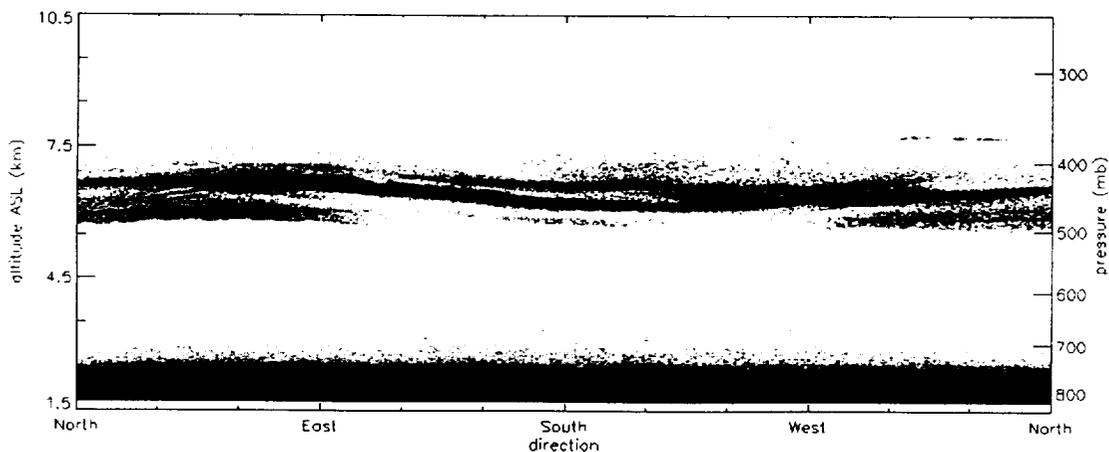


Figure 6: Atmospheric scan from 3/10/99 at 2325 UTC showing undulations at the lower interface (~5.5 km ASL).

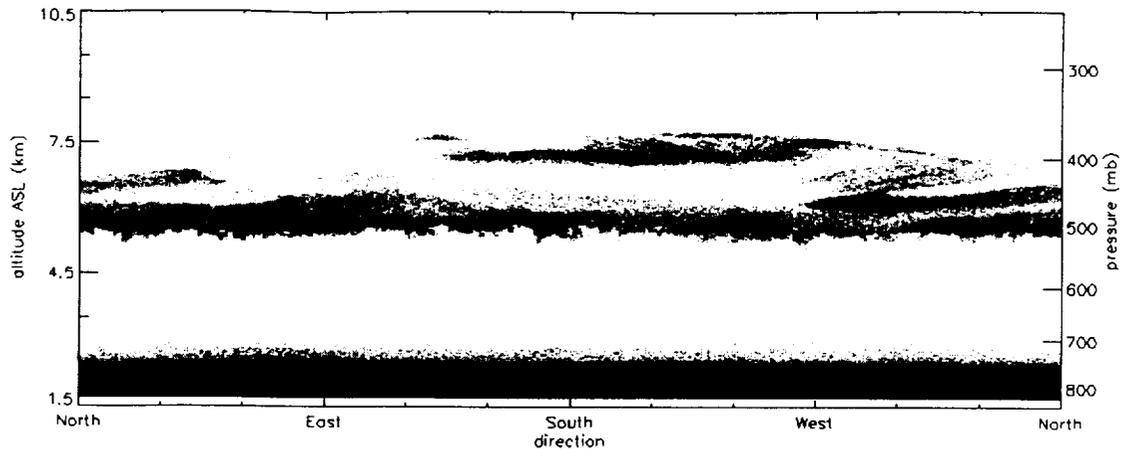


Figure 7: Atmospheric scan from 3/11/99 at 0025 UTC showing the transition to turbulence at the lower interface (~5.5 km ASL).

## 6. Acknowledgments

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